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DESIGN FEATURES OF A SMALL OILFREE, RECIPROCATING, HIGH PRESSURE COMPRESSOR

by

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ABSTRACT

The paper describes the design concept of a small, oilfree, reciprocating high pressure compressor which was particularly developed for NGV-applications (NGV = Natural Gas for Vehicles). It is field proven in several thousand installations in various parts of the world. The compressor head is also used in a small hermetically sealed compression unit for technical gases like N₂, Air, Ar, He, H₂, CO₂, etc..

The compressor compresses the gas from atmospheric pressure to 200 bar. New design solutions for the valves, drive mechanism and high pressure seal are described and discussed.

INTRODUCTION

The compressor introduced in this paper is the result of several years of intensive development and testing. The compressor was particularly designed for NGV-applications where the gas is taken from the mains at about 20 mbar g and compressed to 200 bar (3'000 psi) into the high-pressure tank fitted in the Natural Gas-driven vehicle.

The refueling normally takes several hours until the appropriate fill pressure is reached and the compressor shuts down automatically.

This application is field proven in several thousand NGV-installations.

The heart of the device is a four-stage, oilfree, high pressure compressor head which in modified versions can also be used for the compression of a variety of technical gases like N₂, Air, Ar, He, H₂, CO₂, etc..

Fig.1 shows a cross section of the compressor unit for technical gases using the same basic compressor design as for NGV.

The main features of the compressor are:

- compact design
- hermetically sealed
- quiet, low vibration
- oilfree compression
- wide operating temperature range -40°C/+40°C
- easy serviceable/long service intervals
- suitable for large scale production

These features are the result of a variety of new design solutions like:

- fully balanced scotch yoke drive with linear needle bearings
- small multiple plastic plate valves in all four stages
- clearance seal in the high pressure stage
- integrated interstage connections

The compressor data are listed in table 1.

The compressor performance i.e. flow rate and electrical power consumption are shown in table 2 (1 l/min. = 0.035 cfm).

DESIGN CONCEPT

The gas is compressed oilfree in 4 stages from atmospheric pressure to 200 bar with stage pressures according to table 1. The 4 cylinders are arranged in a cross configuration.

The gas enters the compressor via the support flange and crankcase and passes the inlet valves of stage 1 which are arranged in the piston of stage 1. The interstage connections of the gas are integrated in the cylinder heads and compressor housing. There are no heat exchangers; all the heat is removed through the finned cylinder heads and compressor housing which are made out of cast aluminium.

The stages 1, 2 and 3 are equipped with piston rings of special PTFE-compounds in cylinders of hardanodized aluminium. Various compounds are used, depending on the type of gas and its quality (e.g. water content, ...).

The single crank shaft is supported by two sealed bearings arranged in-between crank pin and rotor of the electric motor which is directly mounted onto the compressor shaft.

The compressor is bolted to the support flange, with the rotor passing through into the stator which is located on the underside of the support flange. Compressor, support flange and motor form a hermetically sealed unit without a shaft seal.

The compression unit is cooled by a separate fan fixed to the motor cover.

SCOTCH YOKE DRIVE MECHANISM

The scotch yoke mechanism described in this paper is not new, but nevertheless interesting.

The piston arrangement and scotch yoke mechanism are shown in Fig. 2.

Two opposed pistons are connected to the same yoke, describing a sinusoidal movement and generating mass forces of the 1st order in the direction of the cylinder axis. The other piston-yoke assembly has the same mass.

The addition of the mass forces of the two piston-yoke-assemblies with their appropriate phase angle and direction results in a constant rotating radial force which can easily be balanced by two rotating counterweights on the shaft.

Only a small hardly noticeable mass torque which is caused by the offset of the two cylinder axes remains uncompensated.

The mass balance together with a relatively smooth torque curve reduce the vibrations to a minimum.

Since the compressor is oilfree, the scotch yoke mechanism is equipped with two linear needle bearings which are preloaded by a well defined interference fit between slide block, needles and yoke. They are greased with a special synthetic grease. Plastic covers on either side of the assembled yoke are protecting the bearings from dirt penetration and loss of lubricating grease.

VALVES

Patented multiple plastic plate valves (see Fig. 3) are used in two sizes for all four stages:

The valve body is made out of injection moulded PEEK. It is slightly pushed down in the centre by the spiral-shaped flat spring. The valve cage guides the flat spring and the valve body and enables the gas to pass through.

The valves perform exceptionally well over many thousand hours of operation. The main features of this valve type are:

- quiet operation (no metallic knocking)
- fast response to pressure changes due to their low weight
- small dead space
- no wear
- cheap to manufacture

CLEARANCE SEAL OF HIGH PRESSURE STAGE

Our answer to the problem of oilfree dynamic sealing at 200 bar and 10 mm cylinder diameter was the clearance seal:

The piston floats freely in the cylinder with a small well defined gap of approx. 5 μm in diameter. A patented ball support for the piston guaranties a side force-free transmission of the force between the yoke part and the piston (see Fig. 4).

The design and materials selection needs further to comply with the following conditions:

- piston and cylinder with the same small thermal coefficient of expansion for low temperature starting and steady state operation
- tribologically suitable material combination for low wear
- corrosion resistant
- no side force induced into piston

The materials for piston and cylinder used for gases like Air, N₂, Natural Gas, CO₂ are hardmetal and ceramic respectively.

A clearance seal running under the right conditions can operate for many thousand hours without any noticeable wear.

The leakage in the clearance is dependent on piston geometry, clearance dimension, piston velocity and type of gas; it is normally in the range of a few percent of the flow rate.

Gases like He, Ar, dry N₂, H₂ require special material combinations and/or coatings for the piston/cylinder combination.

CONCLUSIONS

New design solutions have been proven in thousands of NGV installations.

Applications with other gases have been successfully tested and are further investigated. The next steps of development focus on extending maintenance intervals.

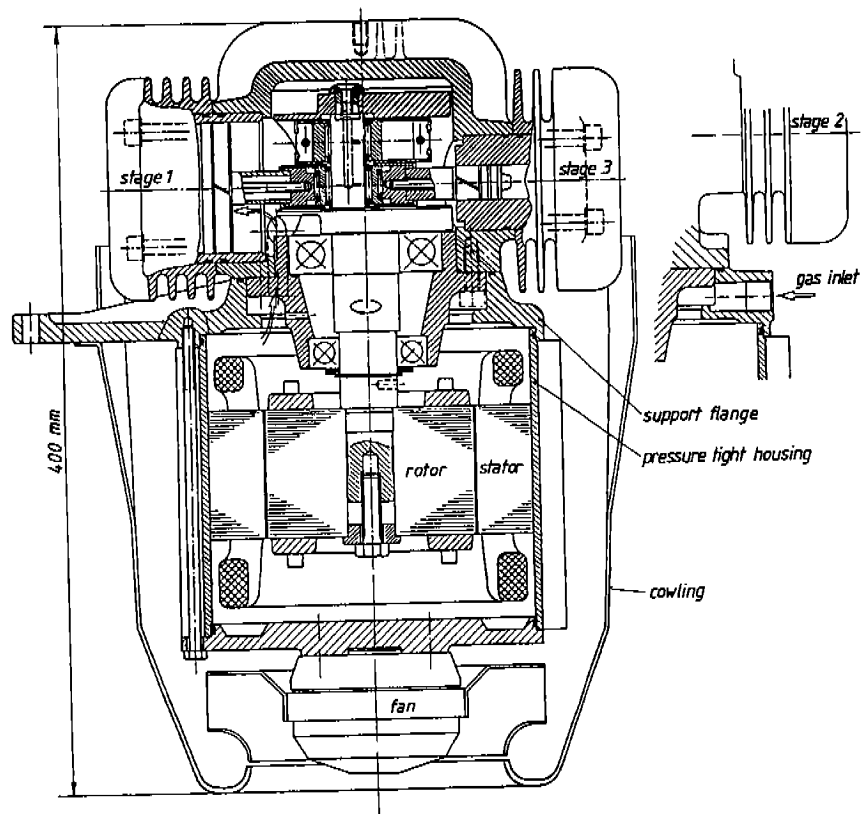


Fig. 1: cross section of compressor

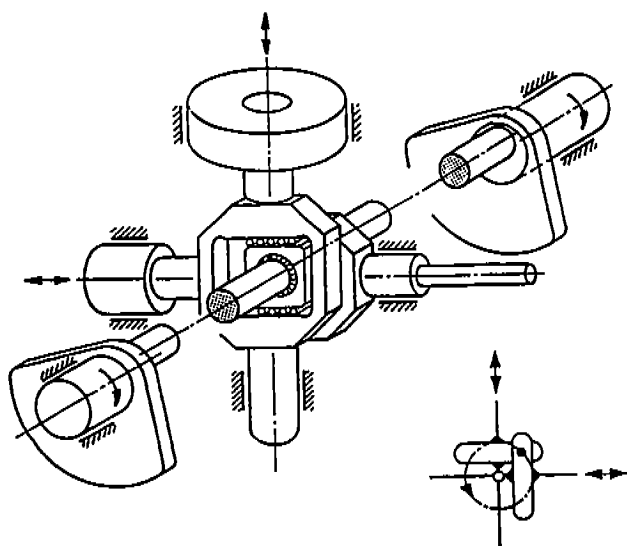


Fig 2: balanced scotch yoke drive

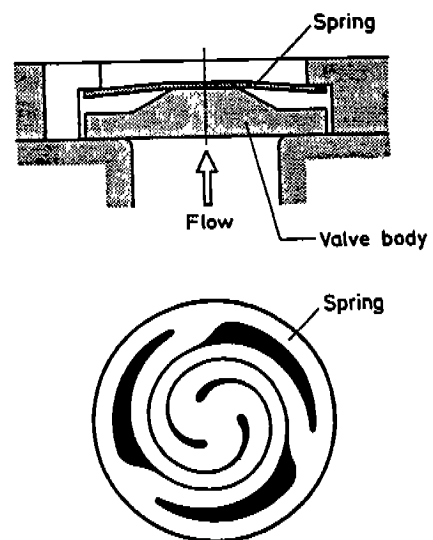


Fig. 3: compressor valve

Stage	Cylinder diameter [mm]	Stage pressure [bar g]
1	68	3.5
2	32	17
3	18	65
4	10	200
Stroke		16 mm
Speed (60 Hz)		1750 min. ⁻¹

Table 1: Compressor data

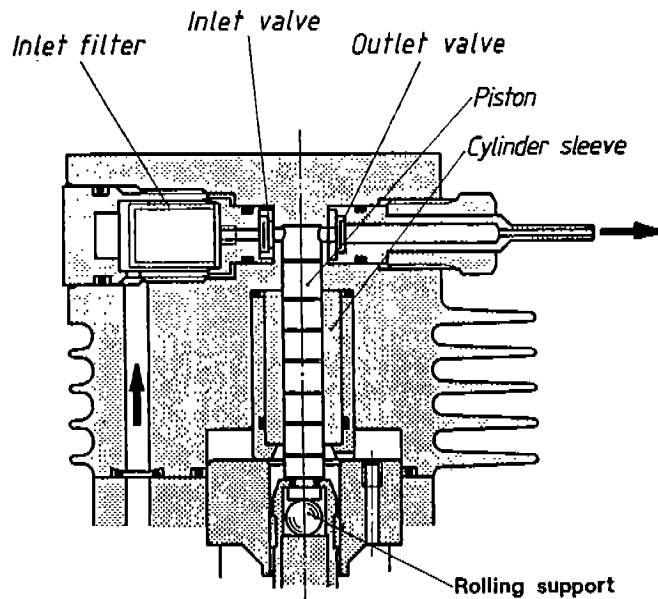


Fig. 4: high pressure cylinder head with clearance seal

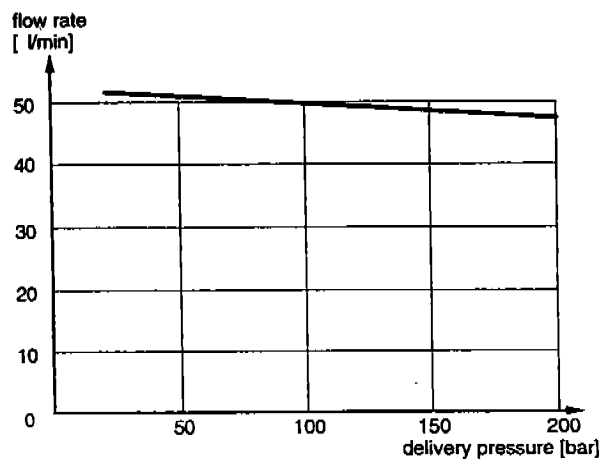
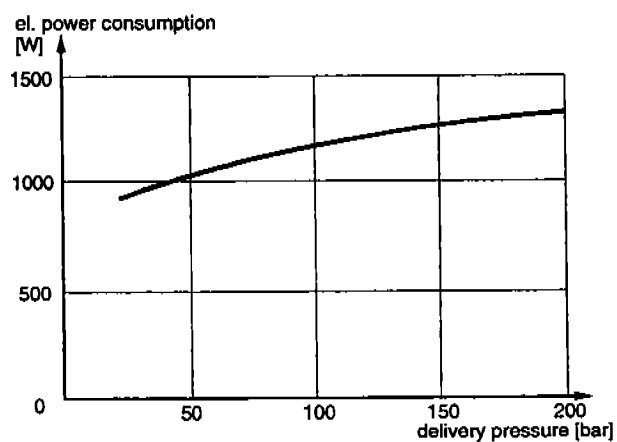


Table 2: compressor performance with nitrogen